NASA TM X-72636

NASA TECHNICAL MEMORANDUM

NASA TM X-72636

COPY NO.

(NASA-TM-X-72636) AERODYNAMIC DAMPING AND OSCILLATORY STABILITY IN PITCH OF A MODEL OF A PROPOSED MANNED LIFTING ENTRY VEHICLE AT MACH NUMBERS OF 1.80, 2.16, AND 2.86 (NASA) 27 p HC $3.75 CSCL 01C G3/02 N75-15609 Unclas 07747

AERODYNAMIC DAMPING AND OSCILLATORY STABILITY IN PITCH OF A MODEL OF A PROPOSED MANNED LIFTING ENTRY VEHICLE AT MACH NUMBERS OF 1.80, 2.16, AND 2.86

By Robert A. Kilgore and Edwin E. Davenport

January 2, 1975

FEB 1975
RECEIVED
NASA STI FACILITY
INPUT BRANCH

This informal documentation medium is used to provide accelerated or special release of technical information to selected users. The contents may not meet NASA formal editing and publication standards, may be revised, or may be incorporated in another publication.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA 23665

1. Report No.
NASA TM X-72636

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Aerodynamic Damping and Oscillatory Stability in Pitch of a Model of a Proposed Manned Lifting Entry Vehicle at Mach Numbers of 1.80, 2.16, and 2.86

5. Report Date
January 2, 1975

6. Performing Organization Code

7. Author(s)
Robert A. Kilgore and Edwin E. Davenport

8. Performing Organization Report No.

10. Work Unit No.

9. Performing Organization Name and Address
NASA Langley Research Center
Hampton, Virginia 23665

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D. C. 20546

13. Type of Report and Period Covered
High-Number TM X

14. Sponsoring Agency Code

15. Supplementary Notes
Special technical information release, not planned for formal NASA publication.

16. Abstract

Wind-tunnel tests were made at angles of attack from about -2° to about 30° at 0° angle of sideslip by using a small-amplitude forced-oscillation technique. In general, all of the configurations have near zero or slightly positive damping in pitch throughout the angle-of-attack range. However, near $\alpha = 25^{\circ}$ at $M = 1.80$ and near $\alpha = 0^{\circ}$ at $M = 2.16$ and 2.86 there is generally a large increase in damping for the configuration having flaps deflected. Deflection of the flaps generally increases the stability of the model except near $\alpha = 0^{\circ}$ at all Mach numbers and at $\alpha \approx 25^{\circ}$ at $M = 1.80$.

17. Key Words (Suggested by Author(s)) (STAR category underlined)
Aerodynamics
Lifting entry vehicle
Supersonic
Dynamic stability

18. Distribution Statement
Unclassified-Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	24	$3.25

*Available from The National Technical Information Service, Springfield, Virginia 22151
STIF/NASA Scientific and Technical Information Facility, P.O. Box 33, College Park, MD 20740

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

AERODYNAMIC DAMPING AND OSCILLATORY STABILITY IN PITCH OF A MODEL OF A PROPOSED MANNED LIFTING ENTRY VEHICLE AT MACH NUMBERS OF 1.80, 2.16, AND 2.86

By Robert A. Kilgore and Edwin E. Davenport

ABSTRACT

Wind-tunnel tests were made at angles of attack from about -2° to about 30° at 0° angle of sideslip by using a small-amplitude forced-oscillation technique. In general, all of the configurations have near zero or slightly positive damping in pitch throughout the angle of attack range. However, near $\alpha = 25°$ at $M = 1.80$ and near $\alpha = 0°$ at $M = 2.16$ and 2.86 there is generally a large increase in damping for the configurations having flaps deflected. Deflection of the flaps generally increases the stability of the model except near $\alpha = 0°$ at all Mach numbers and at $\alpha \approx 25°$ at $M = 1.80$.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

AERODYNAMIC DAMPING AND OSCILLATORY STABILITY IN PITCH OF A MODEL OF A PROPOSED MANNED LIFTING ENTRY VEHICLE AT MACH NUMBERS OF 1.80, 2.16, AND 2.86

By Robert A. Kilgore and Edwin E. Davenport

SUMMARY

Wind-tunnel measurements of the aerodynamic damping and oscillatory stability in pitch of a sub-scale model of a proposed manned lifting entry vehicle have been made by using a small-amplitude forced-oscillation technique. Tests were made at Mach numbers of 1.80, 2.16, and 2.86 at angles of attack from about -2° to about 30° at 0° angle of sideslip. Models were tested with two different canopy designs and with upper and lower control flaps both deflected and undeflected.

In general, all of the configurations have near zero or slightly positive damping in pitch throughout the angle of attack range. However, near $\alpha = 25^\circ$ at $M = 1.80$ and near $\alpha = 0^\circ$ at $M = 2.16$ and 2.86 there is generally a large increase in damping for the configurations having upper and lower flaps deflected.

With the flaps undeflected the model is stable only near $\alpha = 0^\circ$ at the lower Mach numbers and at the higher α's at $M = 2.86$. At other angles of attack the model with the flaps undeflected is generally stable. Deflection of the flaps generally increases the stability of the model except near $\alpha = 0^\circ$ at all

Mach numbers and at $\alpha \approx 25^\circ$ at $M = 1.80$.

INTRODUCTION

In order to design adequate guidance and control systems for any of the proposed manned lifting entry vehicles, it was necessary to know both the static and dynamic stability characteristics of the vehicle for all flight conditions. Therefore, as a part of the NASA support of the program to develop a manned lifting entry vehicle, wind-tunnel tests were made at the Langley Research Center to determine the dynamic-stability characteristics of a proposed lifting entry vehicle. The tests reported herein were made in pitch at Mach numbers of 1.80, 2.16, and 2.86. The tests were made on a sub-scale model at angles of attack from about -2° to about 30° at 0° angle of sideslip by using a small-amplitude forced-oscillation technique. The results of these tests, obtained during three periods of tunnel occupancy in the Langley Unitary Plan wind tunnel during 1965 and 1966, were used during the lifting entry design studies. The results are published herein to provide a contribution to the aerodynamic data base for future studies of lifting body vehicles.

SYMBOLS

Measurements were obtained and are given in the International System of Units (SI). Details concerning the use of SI, together with physical constants and conversion factors, are given in reference 1.

The aerodynamic parameters are referred to the body system of axes, as shown in figure 1. These axes originate at the center of oscillation of the model, as shown in figure 2. The equations used to reduce the data are presented in the section on "Procedure and Reduction of Data".

A	reference area, 0.0963 m^2
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{q_\infty A d}$, (see fig. 1)
C_{m_q}	$\frac{\partial C_m}{\partial\left(\frac{qd}{2V}\right)}$, per radian
$C_{m_{\dot{q}}}$	$\frac{\partial C_m}{\partial\left(\frac{\dot{q}d^2}{4V^2}\right)}$, per radian
C_{m_α}	$\frac{\partial C_m}{\partial \alpha}$, per radian
$C_{m_{\dot{\alpha}}}$	$\frac{\partial C_m}{\partial\left(\frac{\dot{\alpha}d}{2V}\right)}$, per radian
$C_{m_q} + C_{m_{\dot{\alpha}}}$	damping-in-pitch parameter, per radian
$C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$	oscillatory-longitudinal-stability parameter, per radian
d	reference length, 0.5608 m
f	frequency of oscillation, hertz
k	reduced-frequency parameter, $\frac{\omega d}{2V}$, radians
M	free-stream Mach number
q	angular velocity of model about Y-axis, radians/second, (see fig. 1)
q_∞	free-stream dynamic pressure, N/m^2
R	Reynolds number based on 0.5608 m
V	free-stream velocity, m/sec
α	angle of attack, radians or mean angle of attack, degrees, (see fig. 1)
ω	angular velocity, $2\pi f$, radians/second

A dot over a quantity denotes the first derivative with respect to time.

APPARATUS

Models

Design dimensions of the sub-scale models of the configurations tested are presented in the sketches of figure 2. Details of the geometric characteristics of the models are given in table I. The 8% scale models were geometrically similar to the proposed configurations except for the aft portions which were modified to provide adequate clearance for the model-support sting. A single body portion, made of fiberglass reinforced plastic, was used for all configurations. The upper and lower flaps were made of aluminum alloy and were bolted to the model. With the flaps removed, the fiberglass reinforced plastic portion of the model represented the 0° flap deflection configuration. The rudders were fixed in the 10° braked position. The two canopies used were made of mahogany. The surfaces of the models exposed to the airstream were aerodynamically smooth.

A four digit code is used to identify the various configurations. The configuration code as well as the designation of the various model components used herein were assigned by the prime contractor for the proposed vehicle for identification of the various configurations tested. The configuration code is as follows:

Configuration X X X X

- Rudder position in units of 10°
- Lower flap deflection in units of 10°
- Upper flap deflection in units of -10°
- Canopy: $0 \rightarrow C^{6}$
  $1 \rightarrow C^{10}$

Thus, the code 1521 represents the model with the C^{10} canopy, upper flaps set at -50°, lower flaps set at 20°, and rudder braked at 10°. Photographs of configuration 1521 are presented as figure 3.

Oscillation-Balance Mechanism

A view of the forward portion of the oscillation-balance mechanism which was used for these tests is presented in figure 4. Since the oscillation amplitude is small (~1°), the rotary motion of a variable-speed electric motor is used to provide essentially sinusoidal motion of nearly constant amplitude to the balance through the crank and cross-head mechanism. The oscillatory motion is about the pivot axis which was located at the model station corresponding to the proposed center of mass of the full-scale configuration.

The strain-gage bridge which measures the torque required to oscillate the model is located between the model attachment surface and the pivot axis. This torque-bridge location eliminates the effects of pivot friction and the necessity to correct the data for the changing pivot friction associated with changing aerodynamic loads. Although the torque bridge is physically forward of the pivot axis, the electrical center of the bridge is located at the pivot axis so that all torques are measured with respect to the pivot axis.

A mechanical spring, which is an integral part of the fixed balance support, is connected to the oscillation balance at the point of model attachment by means of a flexure plate. The mechanical spring and flexure plate were electron-beam welded in place after assembly of the oscillation-balance and fixed-balance support in order to minimize mechanical friction. A strain-gage bridge, fastened to the mechanical spring, provides a signal proportional to the model angular displacement with respect to the sting.

Wind Tunnel

The tests reported herein were made in test section number 1 of the Langley Unitary Plan wind tunnel. The test section is about 1.2 meters square and about 2.1 meters long. An asymmetric sliding block which varies the area ratio is used to change the Mach number from about 1.47 to 2.86. Relative humidity and total temperature of the air are controlled in order to minimize the effects of condensation shocks. Total pressure can be varied in order to obtain the desired test Reynolds number. A more detailed description of the Langley Unitary Plan wind tunnel is given in reference 2.

PROCEDURE AND REDUCTION OF DATA

Measurements are made of the amplitude of the torque required to oscillate the model in pitch T_Y, the amplitude of the angular displacement in pitch of the model with respect to sting Θ, the phase angle η between T_Y and Θ, and the angular velocity of the forced oscillation ω. Some details of the electronic instrumentation used to make these measurements are given in reference 3. The viscous-damping coefficient in pitch C_Y for this single-degree-of-freedome system is computed as

$$C_Y = \frac{T_Y \sin \eta}{\omega\Theta}$$

and the spring-inertia parameter in pitch is computed as

$$K_Y - I_Y\omega^2 = \frac{T_Y \cos \eta}{\Theta}$$

where K_Y is the torsional-spring coefficient of the system and I_Y is the moment of inertia of the system about the body Y-axis.

The damping-in-pitch parameter was computed as

$$C_{m_q} + C_{m_{\dot{\alpha}}} = -\frac{2V}{q_\infty Ad^2}\left[\left(C_Y\right)_{\text{wind on}} - \left(C_Y\right)_{\text{wind off}}\right]$$

and the oscillatory-longitudinal-stability parameter was computed as

$$C_{m_\alpha} - k^2 C_{m_{\dot{q}}} = -\frac{1}{q_\infty Ad}\left[\left(K_Y - I_Y\omega^2\right)_{\text{wind on}} - \left(K_Y - I_Y\omega^2\right)_{\text{wind off}}\right]$$

Since the wind-off value of C_Y is not a function of oscillation frequency, it is determined at the frequency of wind-off velocity resonance because C_Y can be determined most accurately at this frequency. The wind-off and wind-on values of $K_Y - I_Y\omega^2$ are determined at the same frequency since this parameter is a function of frequency.

TEST CONDITIONS

The tests were made at Mach numbers of 1.80, 2.16, and 2.86 at angles of attack from about -2° to about 30° at 0° angle of sideslip. The tests were made during three periods of tunnel occupancy with slightly different test conditions for each of the three Mach numbers. Reynolds number R based on a reference length of 0.5608 meters, stagnation pressure, and stagnation temperature for the various Mach numbers were as follows:

Mach number, M	Stagnation pressure, N/m^2	Stagnation temperature, K	Reynolds number, R
1.80	46.7×10^3	339	2.93×10^6
	43.8	325	2.91
2.16	53.7	339	2.88
	50.9	325	2.90
2.86	77.3	339	2.88
	77.7	339	2.90

The appropriate value of Reynolds number is given with the graphical presentation of the dynamic-stability data.

The data were obtained at an oscillation amplitude of about 1° (one half of peak to peak) with the model-balance system oscillating at or near the frequency of velocity resonance. The frequency of oscillation varied from 2.83 to 8.10 hertz. The reduced-frequency parameter, $\frac{\omega d}{2V}$, varied from 0.0096 to 0.0212.

DATA CORRECTIONS AND PRECISION

Model-support interference effects were assumed to be negligible and no corrections for these effects were made to the data. The values of mean angle of attack, α, have been corrected for flow angularity in the test section as follows:

Mach number, M	Flow angularity correction, deg
1.80	0.60
2.16	1.39
2.86	0

These corrections apply strictly only for a model at the vertical center of the test section, however, the corrections were applied to all of the data as a first-order correction to the measured mean angle of attack.

For the data presented herein, values of the probable error of the various quantities are as follows:

	Probable error
Mach number, M	±0.002
Mean angle of attack, α, deg	±0.3

Reynolds number, R	$\pm 0.002 \times 10^6$
Damping-in-pitch parameter, $C_{m_q} + C_{m_{\dot{\alpha}}}$, per radian	± 0.2
Oscillatory-longitudinal stability parameter, $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$, per radian	± 0.01
Reduced-frequency parameter, k, radians	± 0.0003

TEST RESULTS

The results of these tests are presented graphically in figure 5 as the variation of the damping-in-pitch parameter, $C_{m_q} + C_{m_{\dot{\alpha}}}$, and the oscillatory-longitudinal-stability parameter, $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$, with mean angle of attack, α. Positive damping in pitch and positive oscillatory stability in pitch are indicated by negative values of $C_{m_q} + C_{m_{\dot{\alpha}}}$ and $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$ respectively.

Typical schlieren photographs obtained at the various Mach numbers are presented as figure 6.

In general, all of the configurations have near zero or slightly positive damping in pitch throughout the angle of attack range. However, near $\alpha = 25^\circ$ at $M = 1.80$ and near $\alpha = 0^\circ$ at $M = 2.16$ and 2.86 there is generally a large increase in damping for the configurations having upper and lower flaps deflected. The exception to the increase in damping with flap deflection is configuration 0521 where the influence of the canopy on the flow field apparently prevents the increase in damping from the upper flaps from being realized. The increased damping at $M = 1.80$ near $\alpha = 25^\circ$ is in agreement with the results published in reference 4 obtained for a similar configuration at these same test conditions.

The oscillatory-stability parameter appears to be more sensitive to flap setting than the damping parameter. With the flaps undeflected (configurations

0001 and 1001) the data show the model to be stable only near $\alpha = 0^\circ$ at the lower Mach numbers and at the higher α's at M = 2.86. At other angles of attack the model with the flaps undeflected is generally stable. Deflection of the flaps (configurations 0521 and 1521) generally increases the stability of the model except near $\alpha = 0^\circ$ at all Mach numbers and at $\alpha \approx 25^\circ$ at M = 1.80.

Examination of the schlieren photographs presented in figure 6 shows that the configurations having grossly different damping and stability characteristics also have detectable differences in shock patterns. For example, at M = 2.86, the change in canopy between configurations 0521 and 1521 is seen to result in a large increase in damping and a large decrease in stability at $\alpha = 0^\circ$. In the schlieren photographs obtained at $\alpha = 0^\circ$ and presented in figure 6c, there is an obvious difference in the shock pattern emanating from the model in the region of the canopy.

CONCLUDING REMARKS

Wind-tunnel measurements have been made of the aerodynamic damping and oscillatory stability in pitch for a sub-scale model of a proposed manned lifting entry vehicle at Mach numbers of 1.80, 2.16, and 2.86. The measurements were made at angles of attack from about -2° to about 30° at 0° angle of sideslip by using a small-amplitude forced-oscillation technique. Models were tested with two different canopy designs and with upper and lower control flaps both deflected and undeflected.

In general, all of the configurations have near zero or slightly positive damping in pitch throughout the angle of attack range. However, near $\alpha = 25^\circ$ at M = 1.80 and near $\alpha = 0^\circ$ at M = 2.16 and 2.86, there is generally a large increase in damping for the configurations having upper and lower flaps deflected.

With the flaps undeflected the model is stable only near $\alpha = 0^\circ$ at the lower Mach numbers and at the higher α's at $M = 2.86$. At other angles of attack the model with the flaps undeflected is generally stable. Deflection of the flaps generally increases the stability of the model except near $\alpha = 0^\circ$ at all Mach numbers and at $\alpha \approx 25^\circ$ at $M = 1.80$.

REFERENCES

1. Mechtly, E. A.: The International System of Units - Physical Constants and Conversion Factors - Second Revision. NASA SP-7012, 1973.

2. Schaefer, William T., Jr.: Characteristics of Major Active Wind Tunnels at the Langley Research Center. NASA TM X-1130, 1965.

3. Wright, Bruce R.; and Kilgore, Robert A.: Aerodynamic Damping and Oscillatory Stability in Pitch and Yaw of Gemini Configurations at Mach Numbers From 0.50 to 4.63. NASA TN D-3334, 1966.

4. Kilgore, Robert A.; and Davenport, Edwin E.: Aerodynamic Damping and Oscillatory Stability of a Proposed HL-10 Vehicle in Pitch at Mach Numbers from 0.20 to 2.86 and in Yaw at Mach Numbers from 0.20 to 1.20. NASA TM X-72610, October 1974.

TABLE I

GEOMETRIC CHARACTERISTICS OF MODEL

Reference area, A, m^2	0.0963
Reference length, d, m	0.5608
Body (without fins), B^{20}	
length, m	0.5752
plan area, m^2	.0956
width, m	.2438
height, m	.1341
Center fin, F^{64}	
airfoil section	slab
area, m^2	0.00927
aspect ratio	.54
leading edge sweep	55°
root chord, m	.1753
tip chord, m	.0875
taper ratio	.499
span, m	.0707
thickness, m	.0101
Tip fins, F^{65}	
airfoil	cambered with leading edge droop
area (true, per fin), m^2	0.01477
aspect ratio	.61
dihedral (angle with respect to vertical)	16°
incidence (leading edge toed in)	4°

TABLE I.- Concluded.

leading edge sweep (projected side view)	55°	
root chord, m	0.2070	
tip chord, m	.0930	
taper ratio	.447	
span (root chord to tip chord), m	.0948	
overall vehicle width (trailing edge tip between fins, theoretical), m	.3252	
Rudder, R^{64}		
area, m^2	0.00297	
hingeline sweep	9.78°	
Rudder, R^{65}		
area, m^2	0.00440	
hingeline sweep	9.78°	
Flaps	Upper, T^{47} and T^{48}	Lower, T^{49} and T^{50}
area, m^2	0.00644	0.00832
chord, m	.0692	0.0914
span, m	.1018	.1079
hingeline sweep	0°	10.47°
Canopies	C^{10}	C^{6}
length, m	0.1956	0.2037
width, m	.0675	.0610
windshield angle	55°	55°

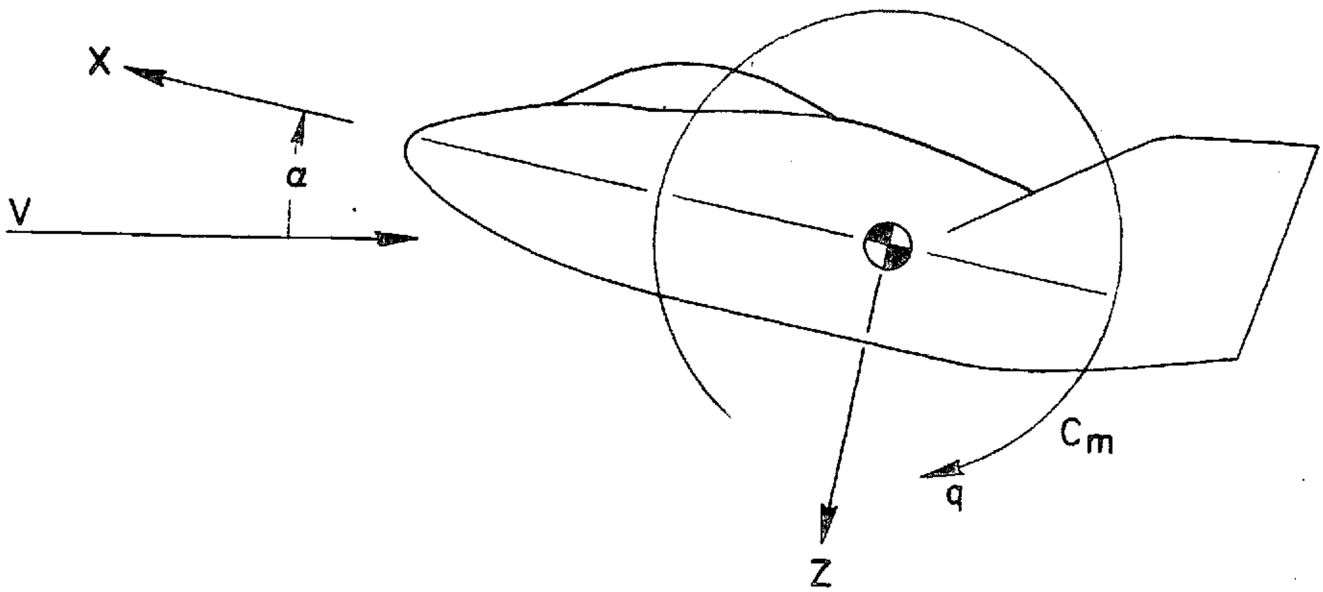


Figure 1.- Body system of axes. Y-axis into plane of figure.

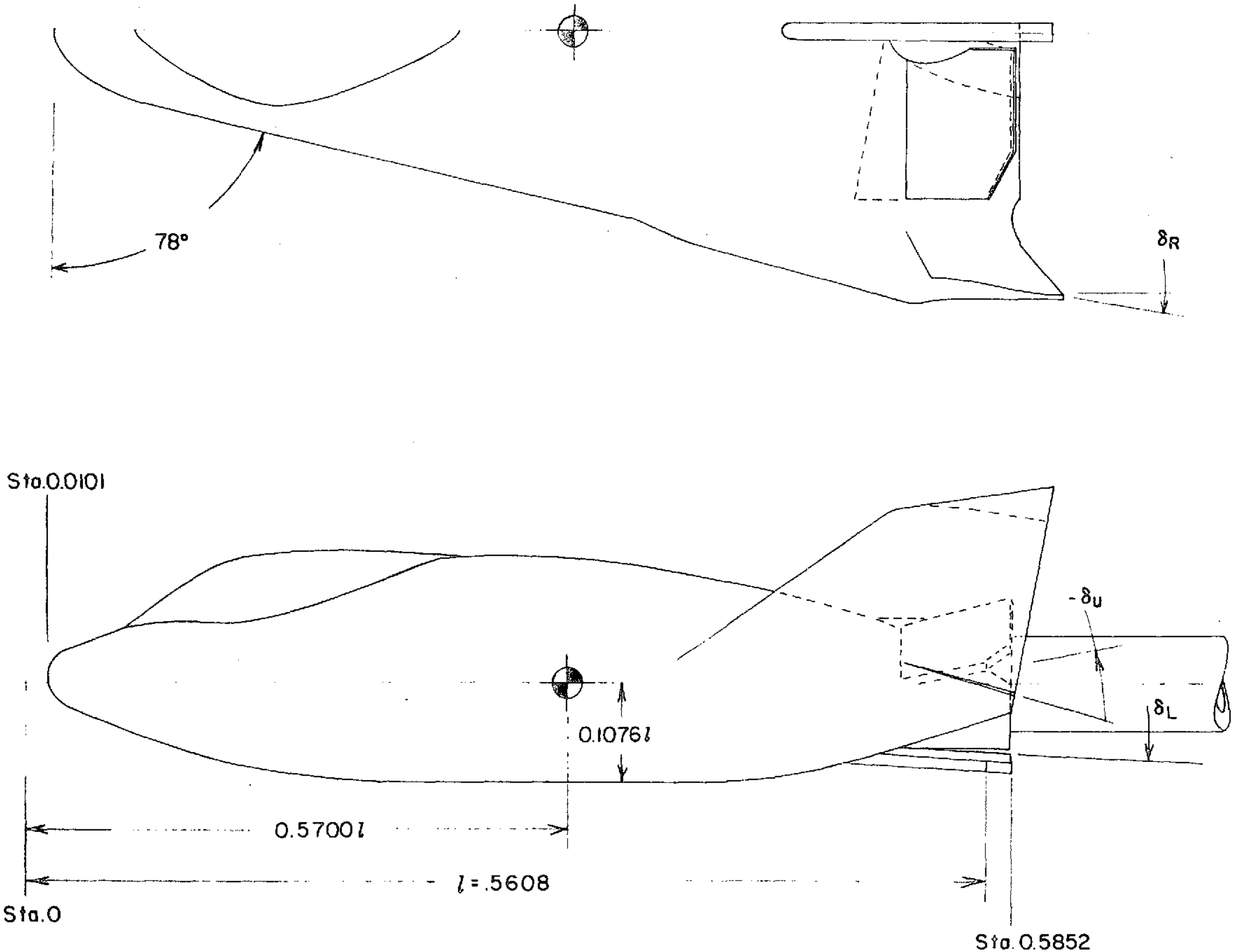


Figure 2. - Design dimensions of model of proposed aircraft.

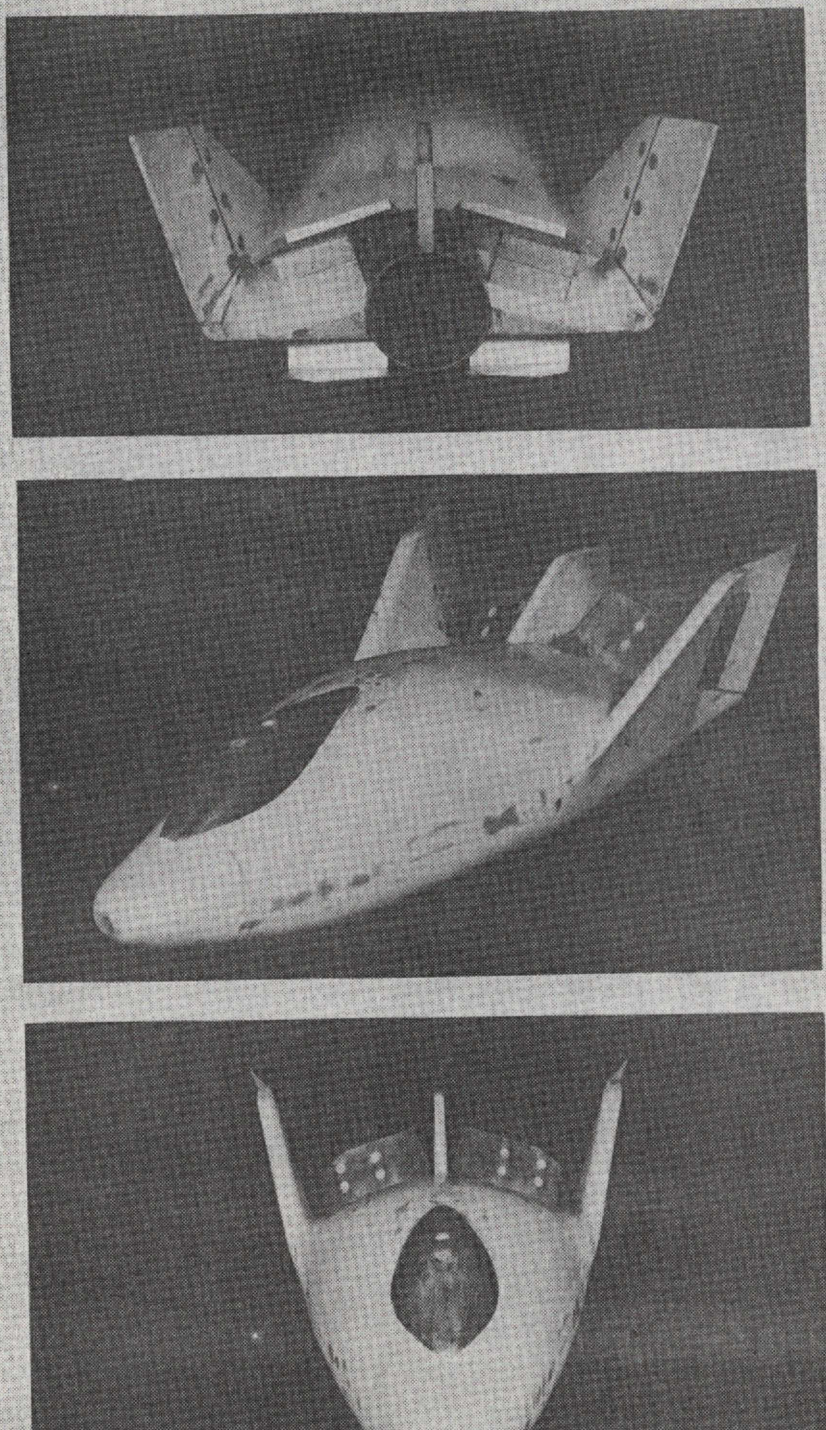


Figure 3.- Photographs of configuration 1521.

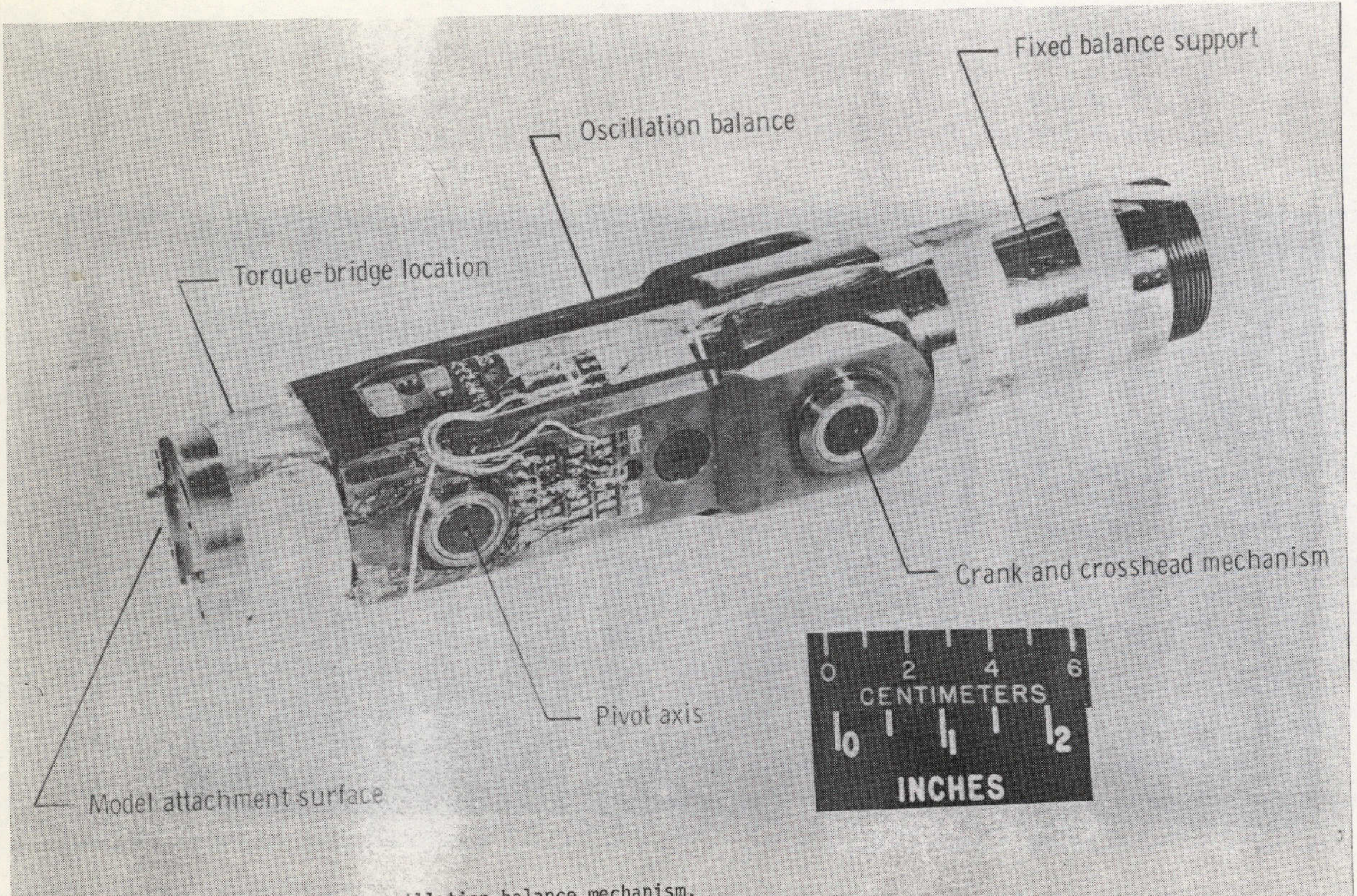
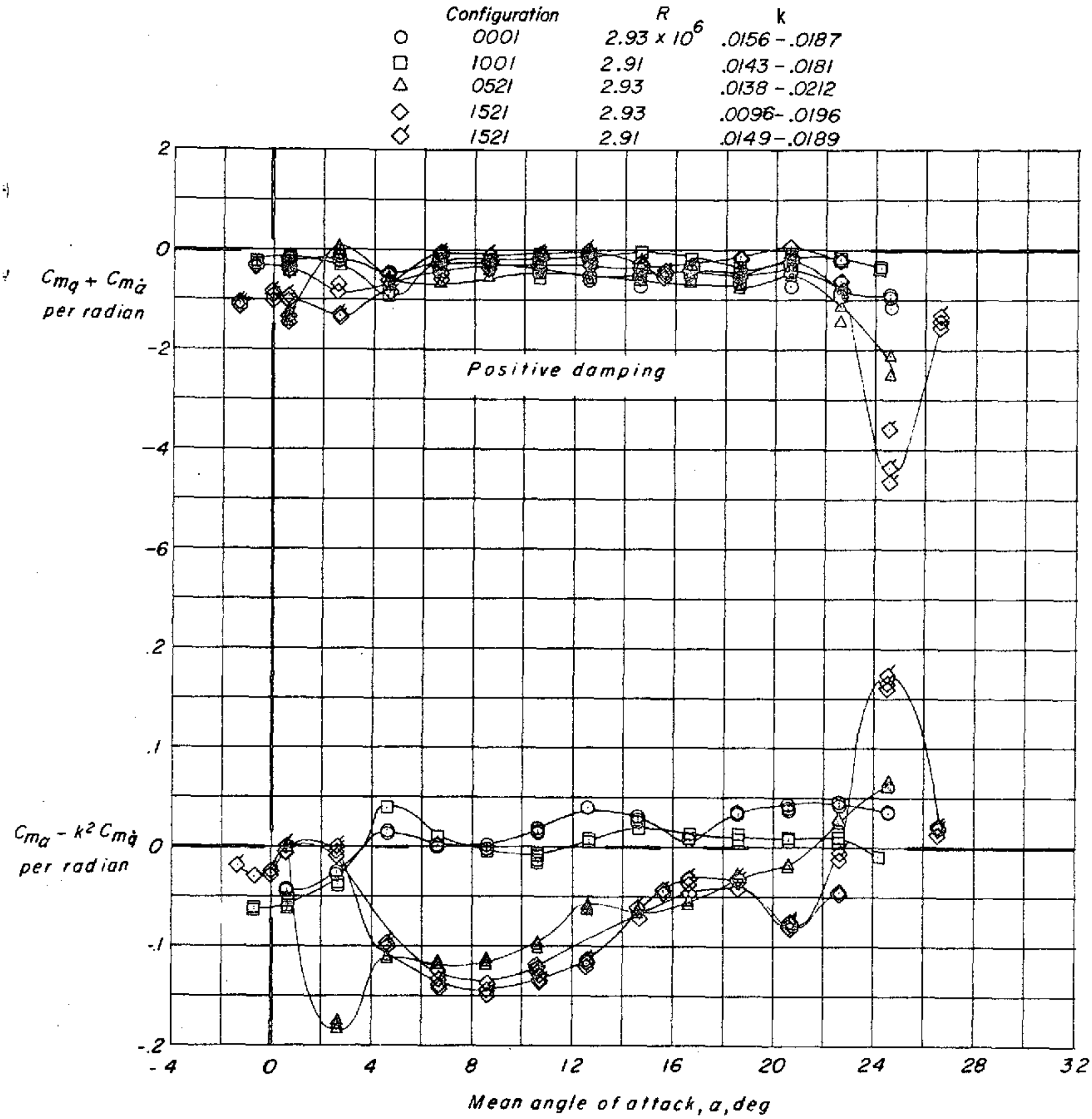
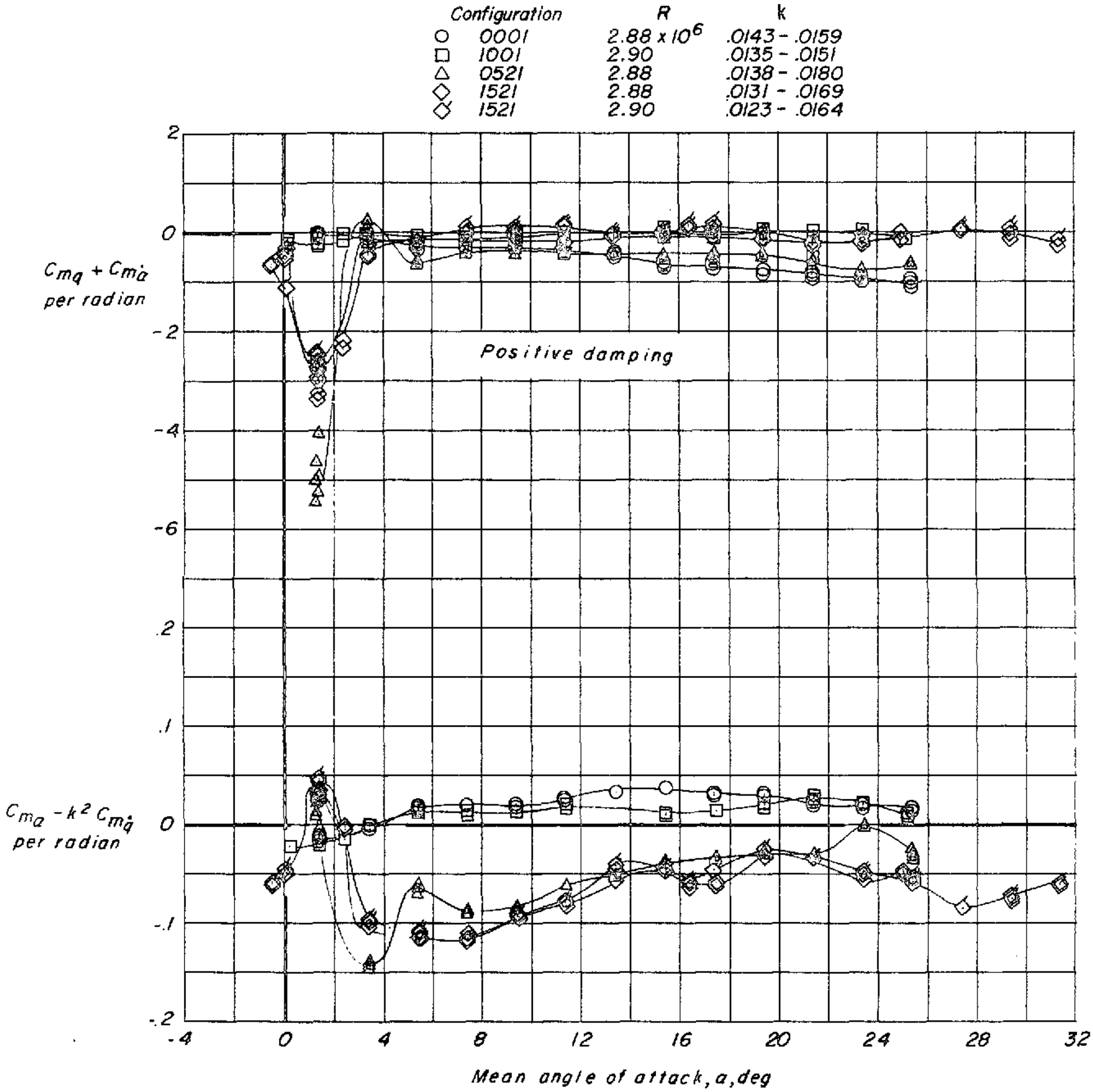


Figure 4.- Forward portion of oscillation-balance mechanism.



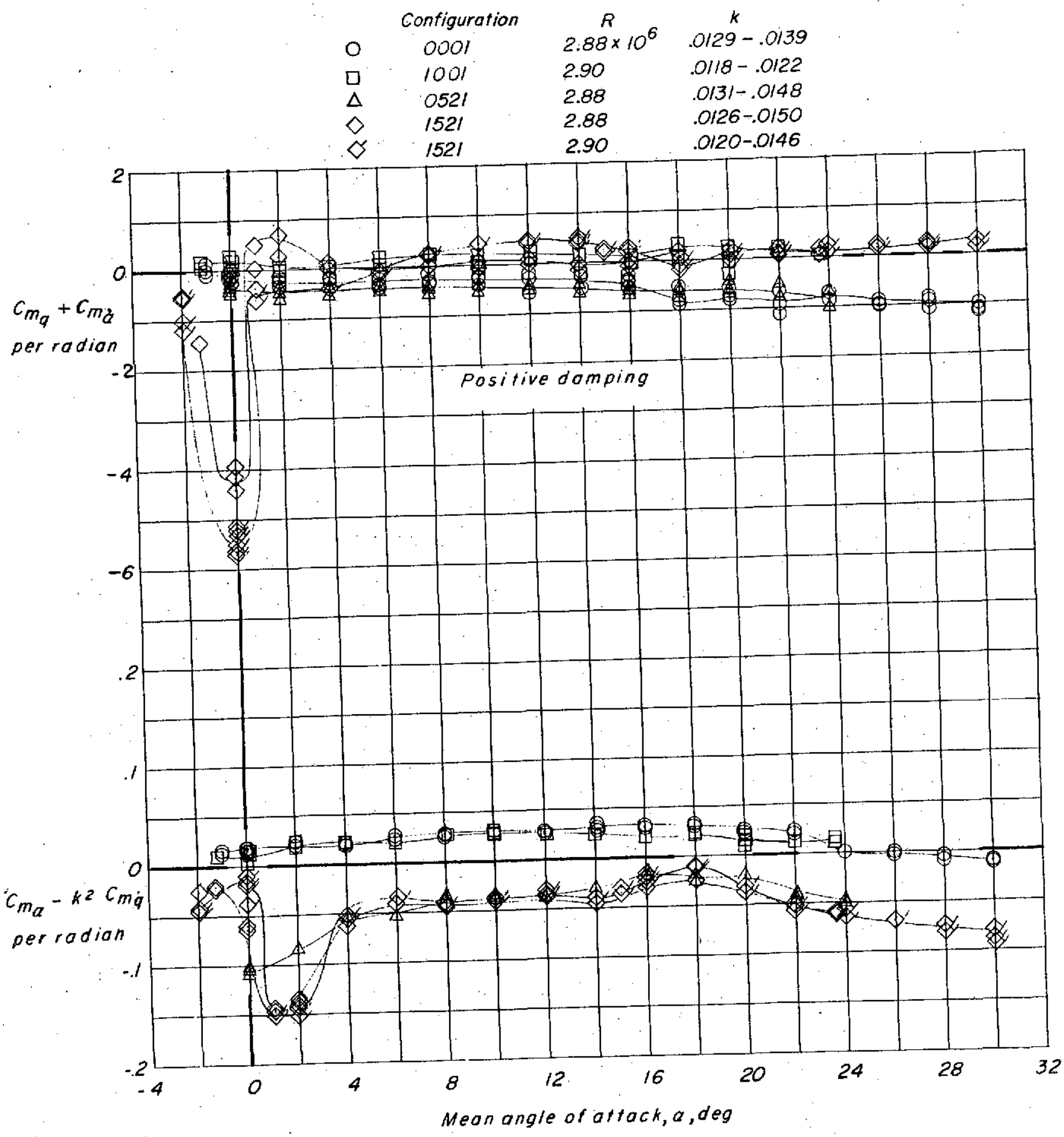
(a) M = 1.80

Figure 5.- Variation of damping-in-pitch parameter and oscillatory-longitudinal-stability parameter with mean angle of attack for various configurations at supersonic speeds.



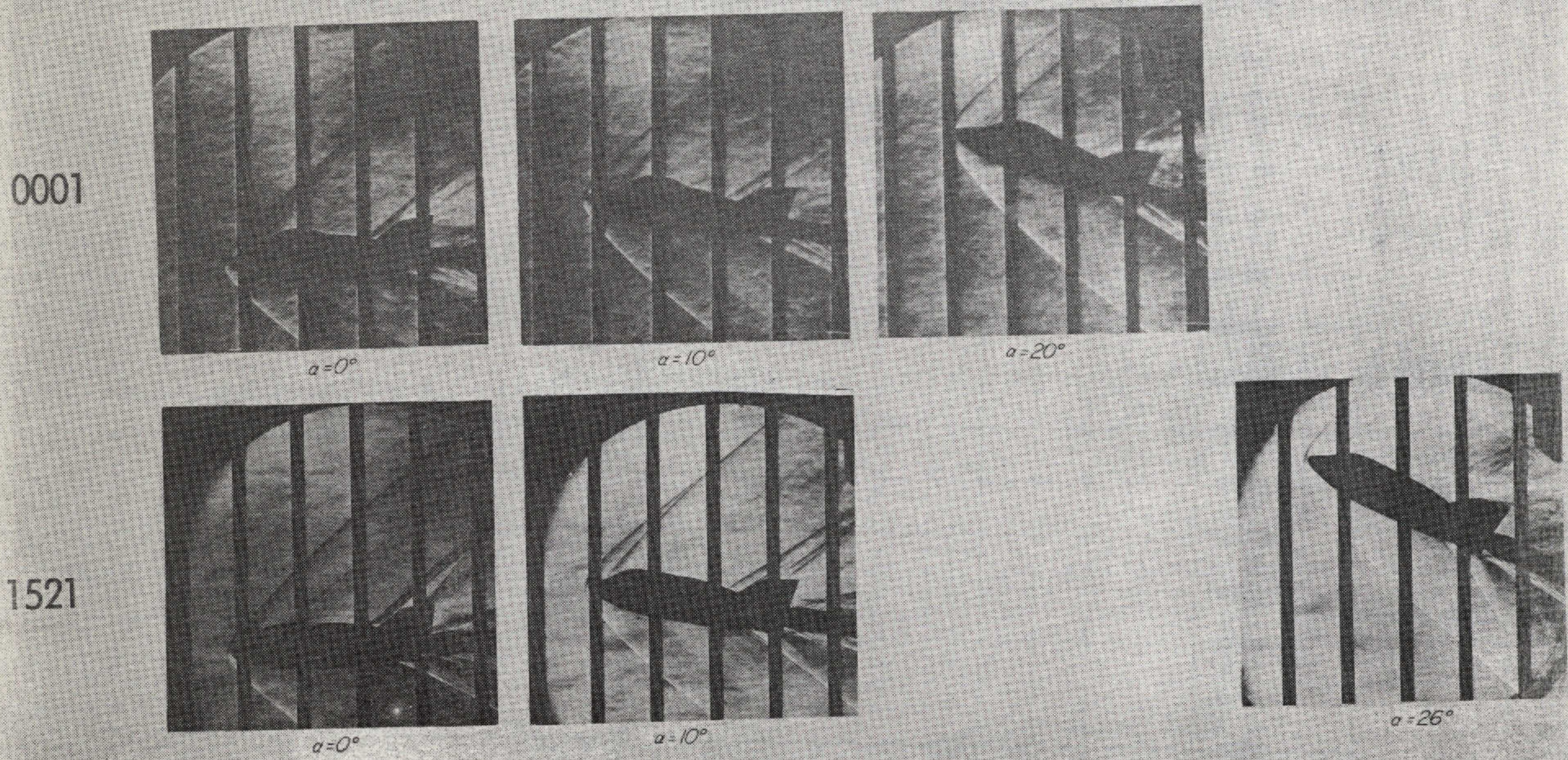
(b) M = 2.16

Figure 5.- Continued.



Configuration R k
0001 2.88 x 10^6 .0129 - .0139
1001 2.90 .0118 - .0122
0521 2.88 .0131 - .0148
1521 2.88 .0126 - .0150
1521 2.90 .0120 - .0146
Cmq + Cmα̇ per radian
Positive damping
Cmα - k² Cmq̇ per radian
Mean angle of attack, α, deg

(c) M = 2.86



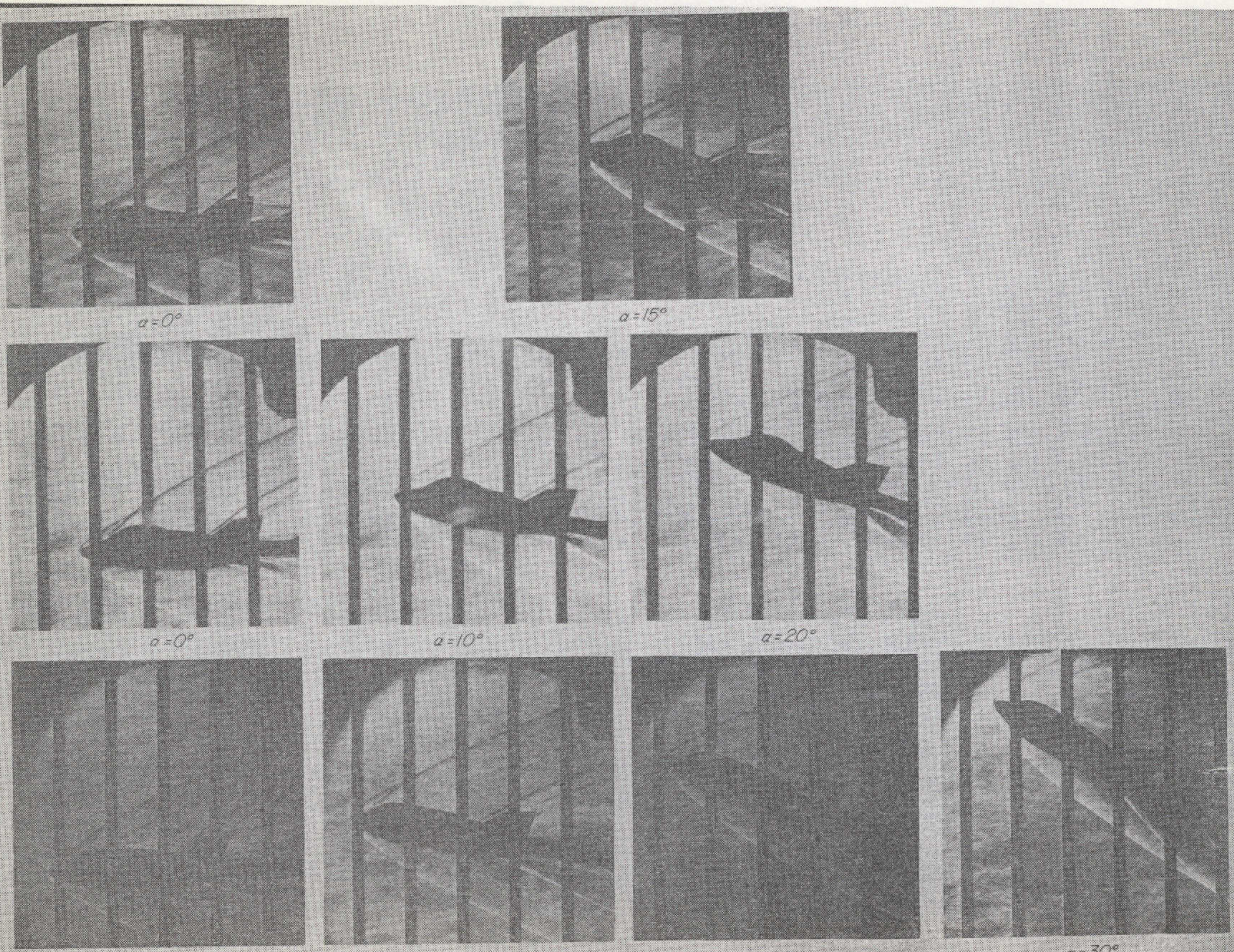
(a) $M = 1.80$

FIGURE 6. - SCHLIEREN PHOTOGRAPHS OF VARIOUS CONFIGURATIONS.

(b) M = 2.16

FIGURE 6. - CONTINUED.

ORIGINAL PAGE IS
OF POOR QUALITY



(c) $M = 2.86$

FIGURE 6. - CONCLUDED.